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MANUAL OF INSTRUCTIONS FOR USE OF THE FIBERGLASS SOIL-MOISTURE INSTRUMENT

MANUAL OF INSTRUCTIONS

FOR USE OF THE FIBERGLAS SOIL-MOISTURE INSTRUMENT

By E. A. Colman
California Forest and Range Experiment Station[1/]
October 1947

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This manual has been prepared for the use of purchasers of the electrical soil-moisture instrument developed by the California Forest and Range Experiment Station. The present instrument is the result of more than ten years of development. It has been subjected to considerable laboratory study and has been tested in limited field installations for several years. Results have been extremely gratifying, and the instrument is therefore considered ready for more extensive field testing.

The soil and meter units of the instrument are not represented as being perfected. Wide field use may show that changes in design or construction are necessary. We wish to be informed of shortcomings and failures of the instrument so that improvements can be made. Only by hearing from users in many places can we appraise the seriousness of defects and make proper plans to cope with them.

It is with this in mind that we suggest that purchasers devote at least some of their soil-units to the job of testing the units themselves. Directions for making a test installation are included in this manual. The California Station is anxious to provide what aid it can in the conduct of these tests. We hope that users will not hesitate to call upon us for assistance and that they will keep us informed as to installations, success of the instrument, and such difficulties as may be encountered in its use.

STEPHEN N. WYCKOFF, Director

1/ Maintained by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of California at Berkeley, California.

DESCRIPTION OF THE INSTRUMENT

Discussion of the basic design and of the uses to which the soil-moisture instrument can be put has been published (The Place of Electrical Soil-moisture Meters in Hydrologic Research, by E. A. Colman, American Geophysical Union Transactions 27(6): 847 853, December 1946.). The instrument now being manufactured has been improved over the one described in that paper, both in materials and design, as a result of nearly two years of additional research

The soil unit is shown in detail in Figure 1. This figure is self-explanatory. It should be noted that the two half-cases of the soil-unit are spot-welded together. They are held together in this way so as to insure uniform spacing between the monel screens of the electrode sandwich. We advise strongly against opening the soil-unit cases. If they are once sprung out of shape, it may not be possible to re-form them properly.

Soil-unit leads are colored as follows: yellow for the thermistor, blue for the electrode sandwich, and black for the lead common to the two.

Each soil-unit has been given a serial number. Space is also provided on the unit case for engraving the thermistor coefficient, which is discussed below.

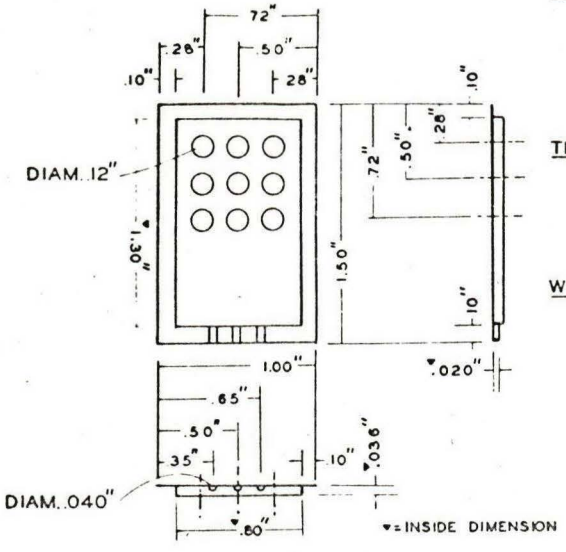
The circuit diagram and panel layout of the meter unit are shown in Figure 2. The circuit elements are listed in the table which accompanies it. The meter is an alternating current ohmmeter, entirely self-powered. Alternating current of 90 c.p.s. is generated in the vacuum tube circuit, passed through the soil unit or the thermistor, and rectified for indication on a d.c. microammeter.

OTHER USES OF SOIL MOISTURE INSTRUMENT

This manual describes the use of the soil-moisture instrument for the specific purpose of measuring soil moisture content. The instrument can also be used to indicate freezing and thawing in soil and snow, and to measure soil-moisture tension. It should also prove useful in irrigation control and can be adapted for automatic irrigation. The paper referred to above describes these uses of the instrument. Laboratory studies of several of these uses have been made. Specific information concerning results of these studies can be obtained by writing the Director, California Forest and Range Experiment Station, 329 Giannini Hall, Berkeley 4, California.

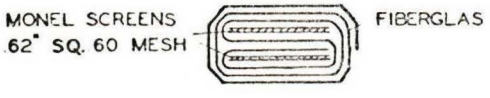
HALF-CASE OF SOIL UNIT

(TWO REQUIRED PER UNIT)
22 GA. SHEET MONEL



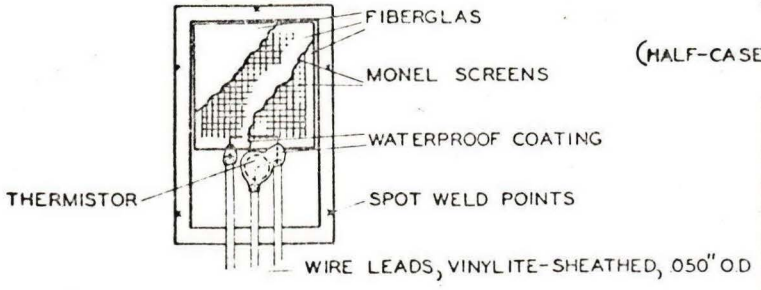
ELECTRODE SANDWICH WRAPPING DIAGRAM

(END VIEW, SCHEMATIC)



ASSEMBLY VIEW

(ELECTRODE SANDWICH CUT-AWAY.
TOP HALF-CASE REMOVED)



SPECIFICATIONS

FIBERGLAS: SILICA FIBERED CLOTH, OWENS-CORNING FIBERGLAS CORP. NO N-11-L05, .007" THICK. FIRED IN CLEAN COMBUSTION TUBE 15 HOURS AT 1060°C ± 10°C. FIBERGLAS MUST BE KEPT CLEAN AND DRY. CUT INTO STRIPS .8" WIDE, APPROX. 6" LONG.

THERMISTOR: WESTERN ELECTRIC CO. NO 7A, DISC TYPE .2" DIAM. .037" THICK. RESISTANCE AT 25°C = 1000 OHMS ± 10%. FINE WIRE LEADS TO BE ATTACHED TO DISC FACES WITH SOLDER (11.5% SILVER, 39.8% TIN, 48.7% LEAD).

WIRE LEADS: MONEL SCREEN WIRES TO BE INSERTED INTO ENDS OF VINYLITE-SHEATHED WIRE-LEADS AND SOLDERED. AT LEAST THREE COATS OF BAKELITE VARNISH, (BAKELITE CORP. FORMULA XV-1657) TO BE USED TO COVER SOLDER CONNECTIONS, VINYLITE SHEATHS AND THERMISTOR ASSEMBLY AS SHOWN. DRIED BAKELITE COATINGS TO BE BAKED AT 120°C FOR 3 HRS. THICKNESS OF COATED THERMISTOR ASSEMBLY NOT TO EXCEED .07". THERMISTOR SOLDER-CONNECTIONS AND LEAD WIRES MUST BE TESTED FOR ELECTRICAL LEAKAGE WHILE IMMERSED IN WATER, BEFORE ASSEMBLY OF UNIT. LEAD-TO-LEAD AND LEAD-TO-CASE RESISTANCE MUST BE CHECKED FOR LEAKS BEFORE SPOT-WELDING HALF-CASES TOGETHER.

NOTES: (SEE ASSEMBLY VIEW)

LOWER EDGE WIRE OF SCREEN TO BE BENT OUT FROM MESH FOR CONTACT WITH WIRE LEADS.

HALF-CASES TO BE SPOT WELDED TOGETHER AT EDGE OF RIM.

ASSEMBLED SOIL UNIT

(HALF-CASE FLANGES SPOT WELDED TOGETHER)

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
CALIFORNIA FOREST & RANGE EXP. STATION
FOREST INFLUENCES DIV. | SAN DIMAS EXP. FOREST

SOIL UNIT
OF
ELECTRICAL SOIL MOISTURE INSTRUMENT
Revised 5/27/47 E.A.C.

DESIGNED BY E.A.C. DRAWN BY T.M.H.
APPROVED BY E A Colman 4.29.47

Figure 1.- Working drawing of Type M soil-unit of the electrical soil-moisture instrument.

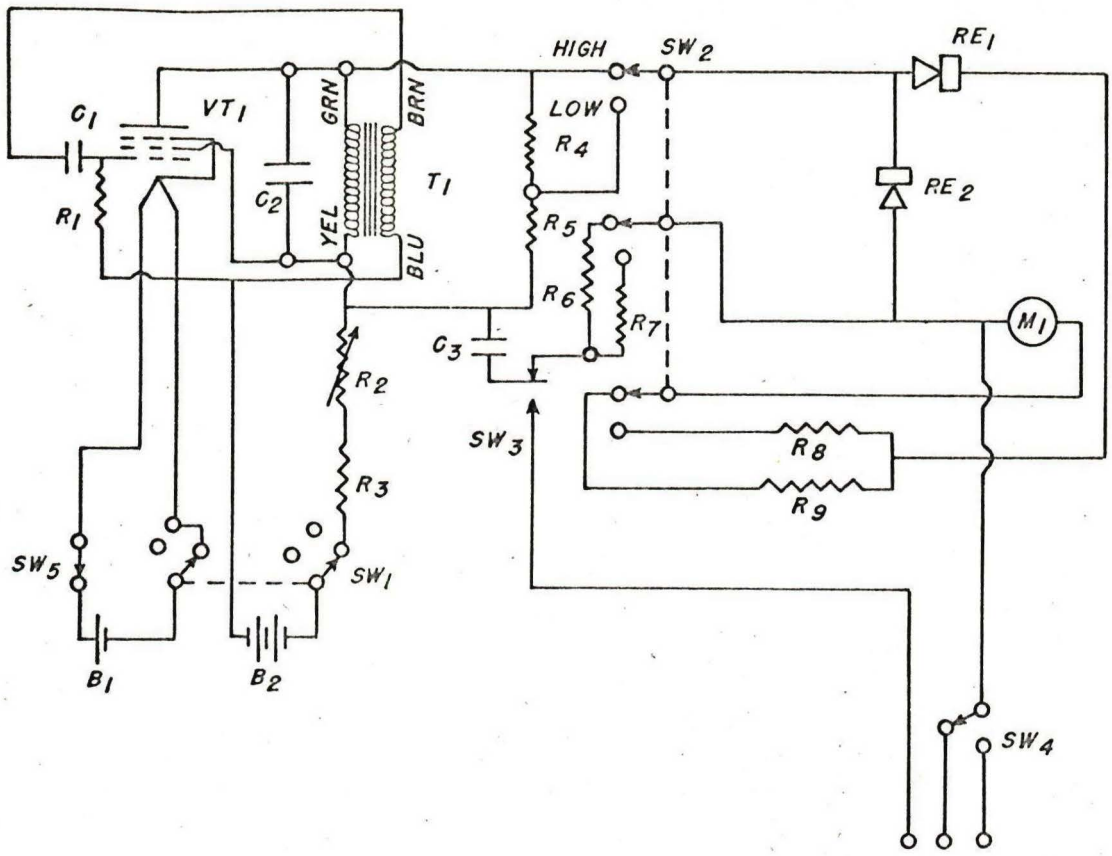
PARTS LIST FOR OHMMETER UNIT OF ELECTRICAL SOIL-MOISTURE INSTRUMENT

Qty.	Part No.	Description	Material and Specifications
1	SW-1	Switch	Double-pole triple-throw rotary
1	SW-2	Switch	Triple-pole double-throw rotary
1	SW-3	Switch	Single-pole double-throw push button
1	SW-4	Switch	Double-pole double-throw rotary
1	SW-5	Switch	Single-pole normally-closed push type
3 ft.		Cable, rubber covered	3 wire
1	R-1	Resistor	1.5 meg-1/2 watt ±10%
1	R-2	Potentiometer	2,000 ohm WW
1	R-3	Resistor	1,200 ohm - 1 watt ±10%
1	R-4	Resistor	15,000 ohm - precision ±1% WW with lugs
1	R-5	Resistor	2,000 ohm - precision ±1% WW
1	R-6	Resistor	7,500 ohm - precision ±1% WW
1	R-7	Resistor	50 ohm - precision ±1% WW
1	R-8	Resistor	*33,000 ohm - 1 watt ±10%
1	R-9	Resistor	*1,200 ohm - 1 watt ±10%
1	C-1	Condenser	1,000 mmF - paper - 600V
1	C-2	Condenser	.25 MF paper - 400V
1	C-3	Condenser	2.0 MF paper - 50V
1	VT-1	Tube	3Q4
1	B-1	Battery	1.5V
1	B-2	Battery	45V
2	RE-1 to 2	Crystal Diode	Germanium
1	T-1	Transformer	Interstage
1	M-1	Microammeter	0-200 microamps

* Selected to calibrate

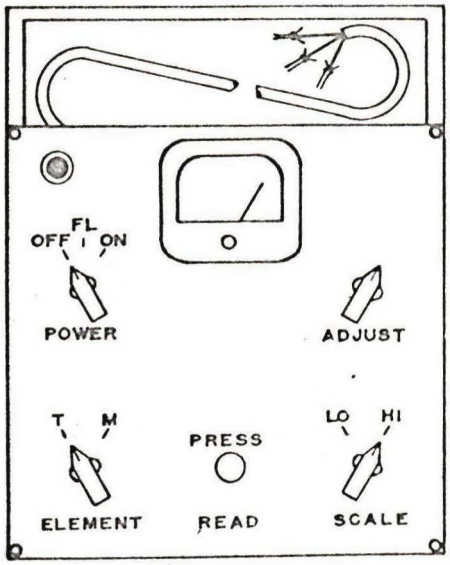
5/17/48

CIRCUIT DIAGRAM



NOTES:
SEE ATTACHED LIST FOR PARTS SPECIFICATIONS.
PANEL LAYOUT NOT DRAWN TO SCALE.
COMPONENT PARTS OF CIRCUIT TO BE MOUNTED ON CHASSIS ONLY.

PANEL LAYOUT



ALTERNATING CURRENT
OHMMETER UNIT
OF
ELECTRICAL SOIL MOISTURE
INSTRUMENT

DESIGN REVISED: 5/17/48 (BERK. SCI. CO.)
FROM DESIGN OF 8/7/47 (CF&RES)

Figure 2.- Working drawing of the A. C. ohmmeter unit of the electrical soil-moisture instrument.

USING THE OHMMETER

First, turn the power switch to "Fil.," which closes the vacuum tube filament circuit, and then (after a second or two) to the "On" position. (Note that S5 is a micro-switch which automatically turns the meter off when the case is closed. This is a safety device to insure maximum battery life.)

Second, set the "Element" switch to T (for temperature) or M (for moisture) measurement. This connects the meter to the appropriate lead wires.

Third, set the "Scale" switch to "Lo" or "Hi" scale. "Lo" scale has an effective range from 50 to 10,000 ohms. "Hi" scale has an effective range from 10,000 to about 3,000,000 ohms. The relation between dial reading of the microammeter and resistance is shown in Figure 3. For measurement of temperature (thermistor resistance), the low scale is always used.

Fourth, turn the "Adjust" knob until the microammeter needle rests at reading 200. You will note that the needle drifts for a short time after the meter has been turned on. Resistance readings made during this time will not be in error provided the needle comes to rest at 200 immediately before and after the reading is made.

Fifth, press the button marked "Read," and read the needle indication on the microammeter dial. Always see that before and after the "Read" button is pressed, the needle rests at 200. The resistance, in ohms, corresponding to any dial reading, is determined by reference to the calibration chart, Figure 3.

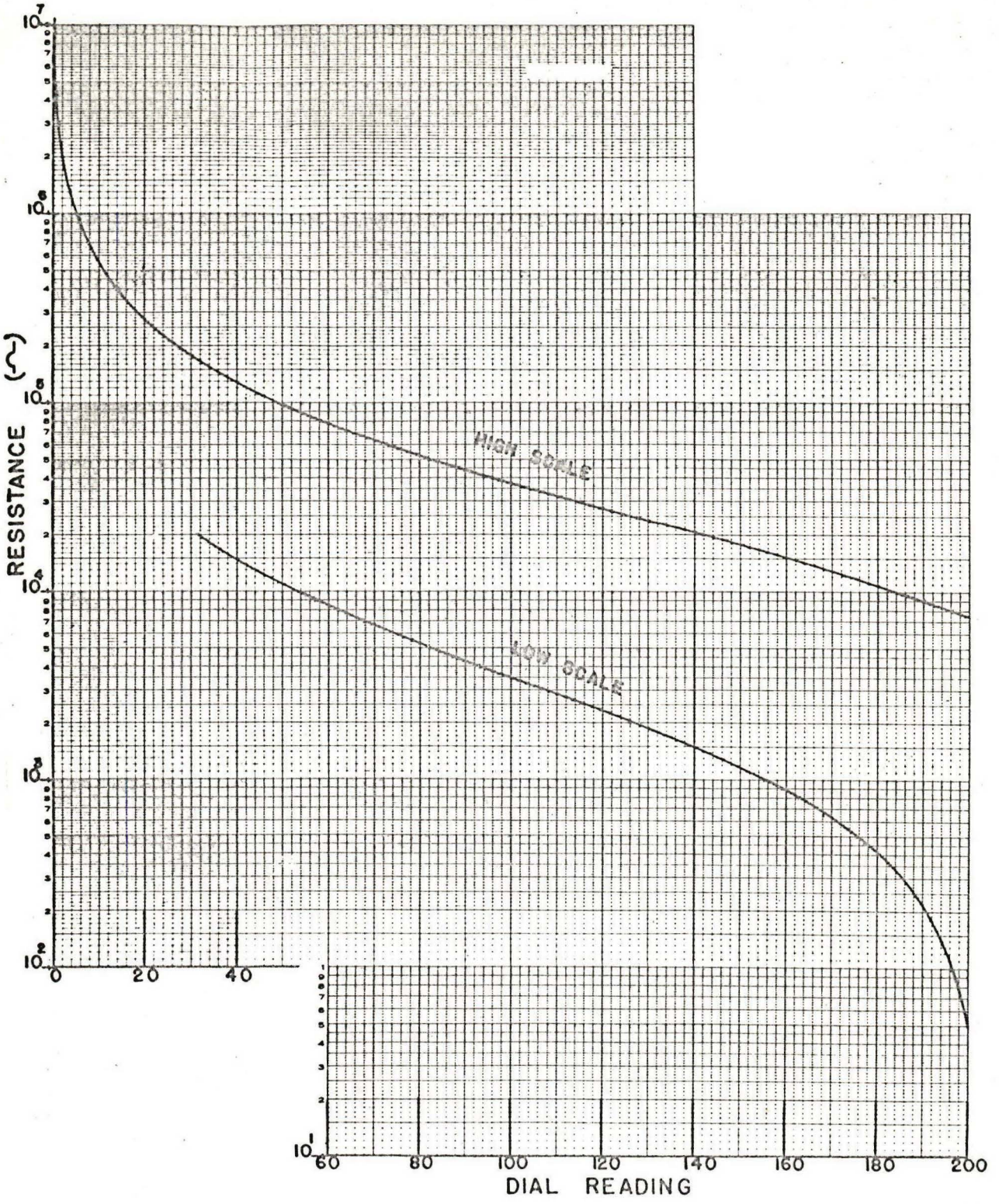


Figure 3.- Calibration chart for A. C. ohmmeter constructed according to Figure 2.

STANDARDIZATION

It would be advantageous if a large number of soil-units, all set in a single mass of soil, under uniform moisture and temperature conditions, all had the same resistance. This would mean that all the soil-units were closely similar in construction and that differences noted between units set in different soils would be due to soil, and not unit, differences. It would also simplify calibration of the soil units and would make possible the development of standard relationships between unit resistance and temperature, soil moisture, or soil-moisture tension.

Preliminary studies made with the present type of soil-unit have, in fact, shown that there is very little difference between the moisture: resistance relations of duplicate soil units, chosen at random, when placed in the same soil. This is encouraging, but, since these studies were conducted on a small scale, they cannot be considered conclusive.

To date, no method has been developed for standardizing the electrode sandwich resistance. Every effort has been made to insure the most uniform materials, construction, and assembly. Further work in laboratory and field will be required to show the need for rating electrode sandwich resistance under standard conditions.

The thermistor in the soil-unit presents a different picture. This element is a tablet of metal oxide, silver-coated on its opposing faces. Electrical resistance measured through the tablet varies with temperature. These thermistors are obtained from the Western Electric Company. They have a nominal resistance of 1000 ohms at 77° F., and individual thermistors are supposed to have resistances within 10 percent of this value. Figure 4 presents the resistance: temperature relation of the thermistor. The middle line shows the nominal relation. The other two lines lie 10 percent above and 10 percent below the middle line, measured in terms of resistance.

Since thermistor resistance changes about 2.5 percent per degree F., it is necessary to determine correction coefficients for them. The determination of the thermistor coefficient can be accomplished in the following manner:

(1) Determine the resistance of the thermistor and the temperature at which this resistance is measured.

(2) Read from the calibration chart (Figure 4) the nominal resistance corresponding to the temperature at which the thermistor was measured. This resistance is read on the middle line of the chart.

(3) Divide the nominal resistance by the measured thermistor resistance. The quotient is the thermistor coefficient. This coefficient can be engraved on the soil-unit case, and should be recorded elsewhere before the unit is buried in the soil. (At present the thermistor coefficient is engraved on the case by the manufacturer, as, for example: t = 1.05.)

For subsequent temperature determinations, the thermistor resistance is multiplied by its coefficient and the corrected resistance is then referred to the middle line of the chart.

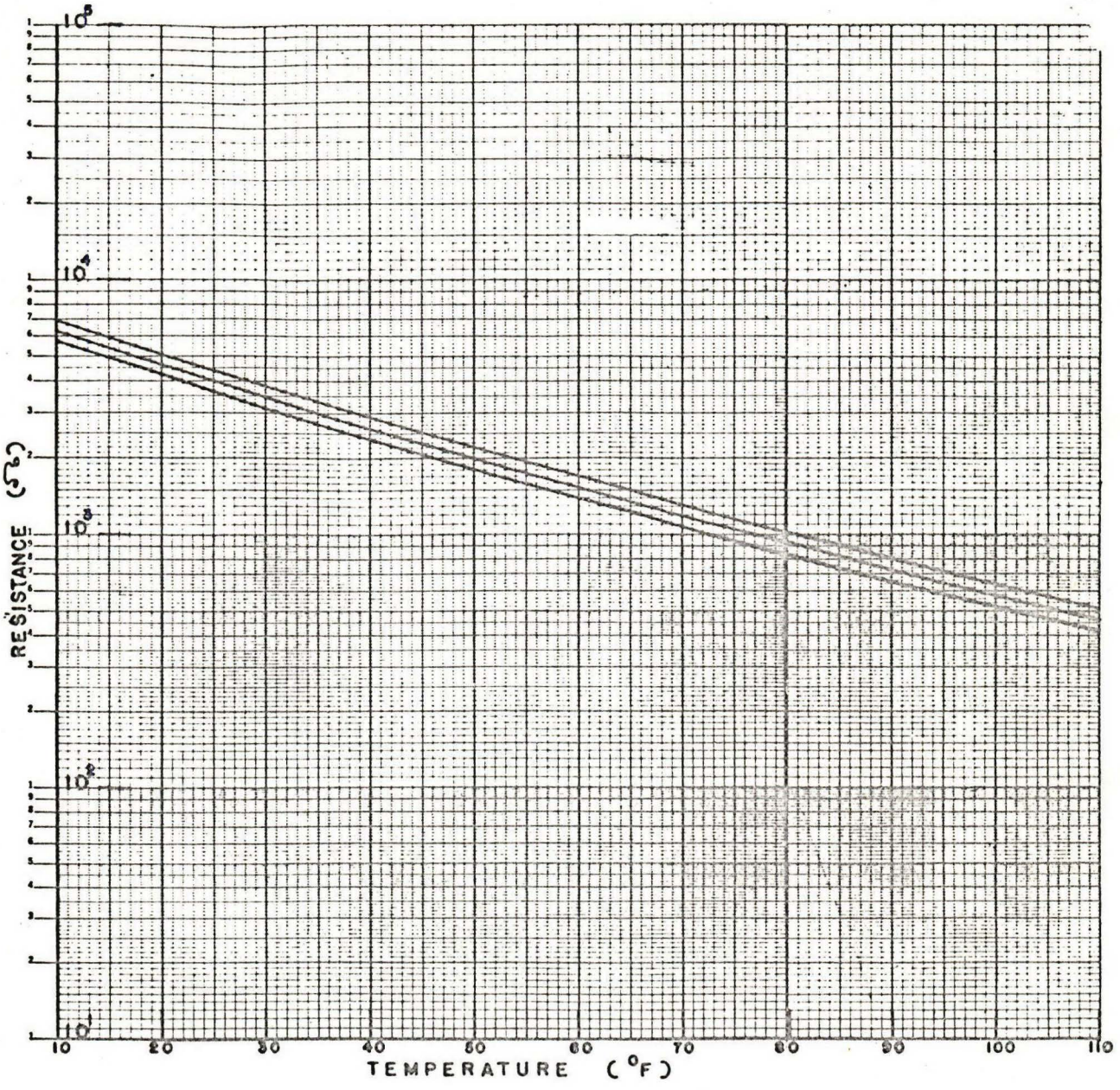


Figure 4.- Calibration chart for Western Electric type 7 A thermistor. Middle line is standard.

TEMPERATURE CORRECTION OF ELECTRODE SANDWICH RESISTANCE

The resistance of the electrode sandwich varies with temperature as well as soil moisture content. For this reason, it is necessary to convert the resistance measured at field temperature to the resistance that would have been measured at some standard reference temperature. The standard temperature chosen for this instrument is 60° F.

The chart shown in Figure 5 provides a simple method for making the temperature correction. The chart is based upon laboratory studies with soils representing a wide range in texture. It is used as follows:

(1) Enter the measured resistance on the dashed (60° F.) line.

(2) Read the corrected resistance vertically above or below the dashed line at the temperature of measurement. The resistance so determined is thus corrected to a temperature of 60° F.

INSTALLATION OF SOIL-UNITS FOR MOISTURE MEASUREMENT

I. Preparation of Soil-Units

The soil-unit is supplied with three 6-inch long leads, color-coded as described earlier. For field installation it is necessary to attach the leads to a waterproof cable long enough to reach from the point of installation to some convenient measurement location. At the measurement location provision must be made for waterproof connections to the meter. Where more than a single soil-unit is used within a small area, it may be desirable to make use of a multiple pole switch at the meter connection.

Neoprene-covered 3-conductor cable can be used between the soil-unit and meter connection. Usually the individual wires in such a cable are color-coded. If a color is assigned for each soil-unit lead, confusion at the meter connection can be avoided. It is important to maintain the identity of each lead from soil-unit to meter because, once the soil-unit is buried, it may be difficult to distinguish them. Therefore, if the cable wires are not color-coded, they should be identified in some other way before the unit is placed in the soil.

All wire connections must be made waterproof and resistant to weathering. If this is not done, high-resistance shorts may develop between leads, resulting in erroneous measurements. It is suggested that connections between soil-unit leads and cable wires be soldered, using non-corrosive flux, the solder connections then coated with Bakelite waterproof insulating varnish, and wrapped tightly with a pressure-sensitive insulating tape made of vinylite or other weather-resistant plastic. Scotch electrical tape, type #33, made by the Minnesota Mining and Manufacturing Company, is suitable for this purpose.

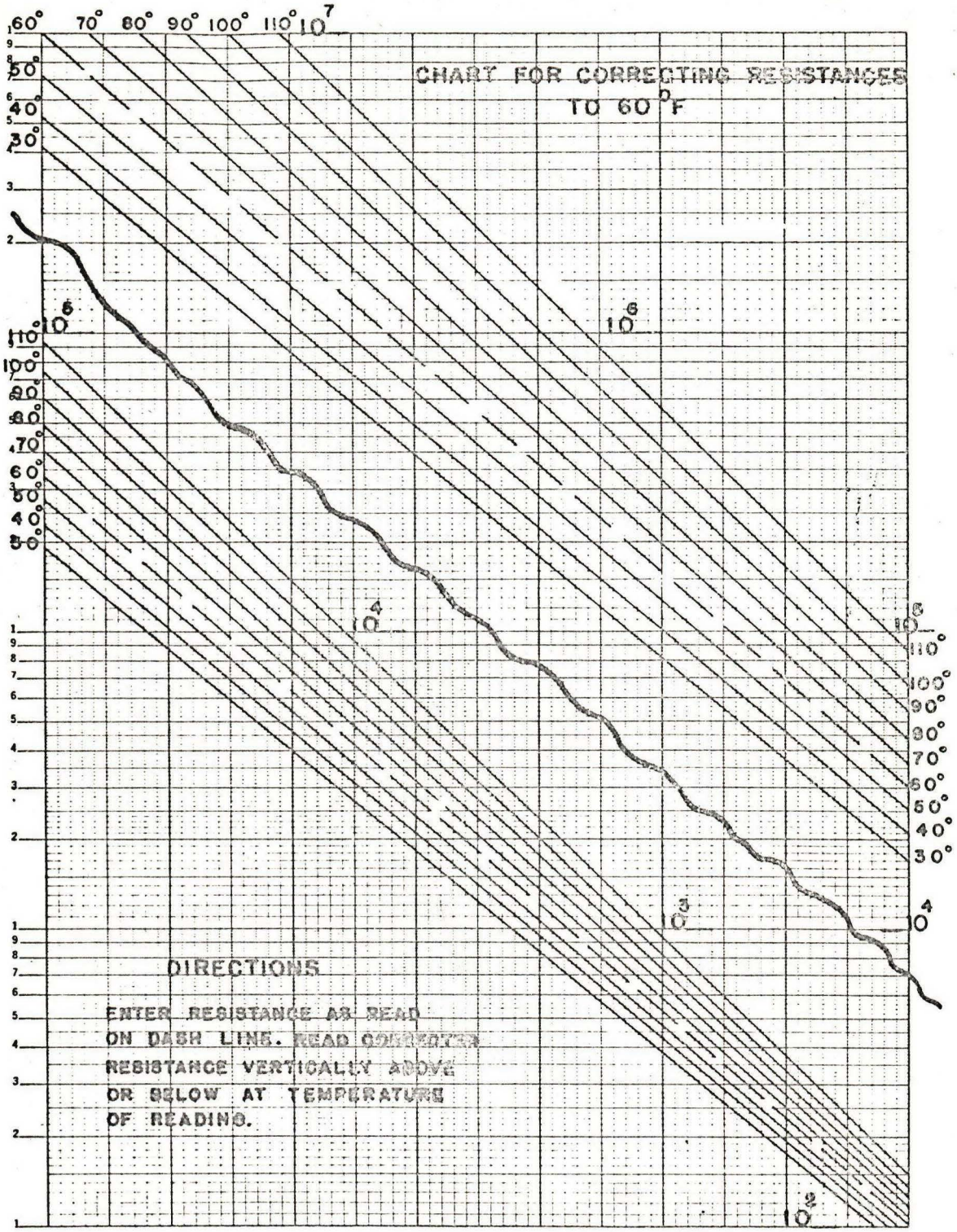


Figure 5.- Chart for correcting soil-unit resistance measured at field temperature to resistance at 60° F.

At the meter location the cable must have a waterproof terminal. Here some kind of weatherproof shelter must also be provided so that shorts will not develop during wet weather. Soldered connections used here should be coated with waterproof insulating varnish. A satisfactory varnish is a short-oil air-drying varnish compounded according to Bakelite Corporation formula XV-1657 . Varnish manufacturers can supply this.

A triple-leaf, multiple-pole switch can be used at a meter location designed to handle more than one soil-unit. In this kind of installation the meter would be connected across the switch and a different soil-unit brought into the meter circuit at each switch position. This type of installation greatly simplifies the measurements of temperature and resistance of a group of soil-units.

II. Placing Soil-Units in the Ground

Soil-units can be placed in holes drilled with an auger or they can be pressed directly into moist or yielding soil from the edge of a pit. It is important that good contact be maintained between the outside of the fiberglas sandwich and the soil. This insures prompt response of the electrode sandwich to changes in soil moisture.

For single installations the soil-unit can be dropped, on the end of its cable, to the bottom of an auger hole, and the soil which was removed from the hole then tamped back in place around and above it. For multiple installations (soil-units at several depths) the soil-units can be dropped into the hole as the replaced soil rises to each desired depth. In such an installation, the hole must be large enough to accommodate the cables as well as the soil-units.

The soil-units can be set in place either flat or on edge. There may be some advantage in orienting them parallel to the most usual direction of water movement, so that they will offer no impediment to such movement. In most field studies this means placing them on edge. Choice of orientation will, however, depend upon the type of information desired from a particular installation.

To insure against the possibility of water flow down along the soil-unit cables, these cables should not pass vertically from the soil-units up through the soil surface. Instead, they should extend horizontally for about a foot, three inches or so beneath the surface, before being brought above-ground. In this connection also, the importance of adequate tamping must be recognized. In refilling an auger hole in which soil-units have been placed, it is important that the soil be tamped tightly enough to prevent the auger hole from becoming an abnormal water passage. This means packing the soil in the auger hole at least to the density of the soil around it.

III. Correction for Apparent Resistance of Three-Conductor Cable

The alternating current ohmmeter is calibrated in ohms resistance, but because of the use of alternating current the indicated resistance is influenced by the amount of capacitance as well as resistance in the measured circuit. This introduces no complications in the use of the soil-moisture instrument when lead-wires are short. But when lead-wires are long, corrections must be made for the apparent resistance of the wires in the cable, which act as a condenser. The apparent resistance (reactance) of the pair of wires in a three-conductor cable can be considered to be in parallel with the combined reactance and resistance of the soil unit. Therefore, the following equation for parallel resistances can be used to calculate soil-unit resistance:

$$\frac{1}{R\ (\text{soil unit})} = \frac{1}{R\ (\text{measured})} - \frac{1}{R\ (\text{cable})}$$

R (measured) is the resistance shown by the ohmmeter, and R (cable) is the meter-read resistance between the cable wires when the far ends of these wires are disconnected and fully insulated from each other. R (cable) will remain constant for any particular soil unit once that unit is installed. Therefore, it can be measured before the soil unit is connected to the cable which will lead from its point of installation to the point of measurement.

Figure 6 presents a chart that can be used for converting from measured resistance to soil-unit resistance. If less than 30 feet of three-conductor cable is used, the cable resistance will probably exceed 1 megohm. In that case, no significant corrections need be made at measured resistances of less than 50,000 ohms. Shorter cables, of course, show higher values of cable resistance, and raise the minimum measured resistance at which corrections need be made. When three-conductor cables less than ten feet long are used, it is unlikely that a correction will ever be needed.

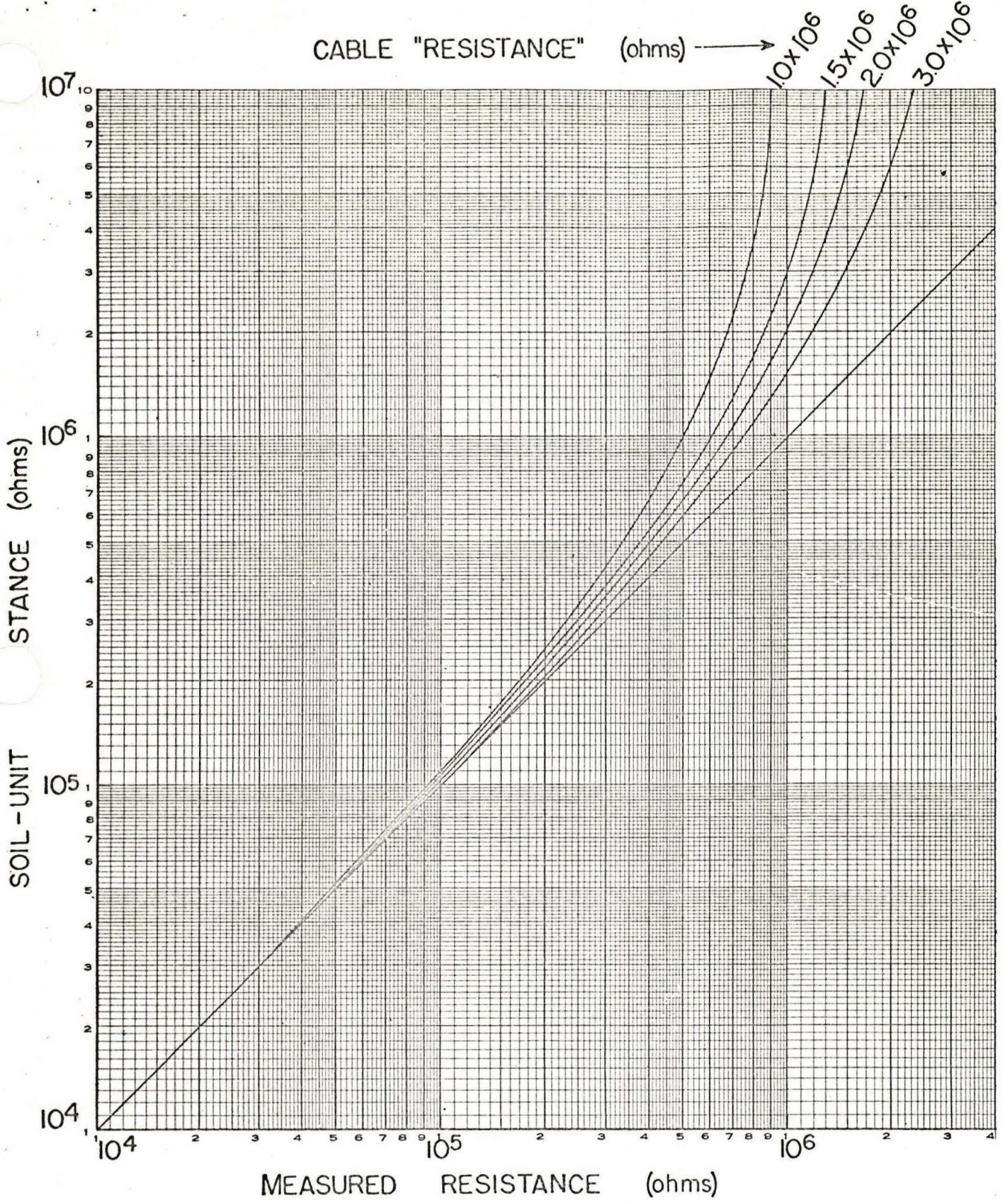


Figure 6.- Chart for determining soil-unit resistance when cable and measured resistances are known.

PROPOSED ADDITIONAL INSTALLATION FOR TESTING SOIL-UNITS

The following instructions relate to installations designed specifically for testing the field performance of soil-units over long periods. The importance of such an installation has already been mentioned, and its value in relation to further development of the instrument emphasized. We hope that all purchasers of soil-units will make some such installation as the one described, and that results from it will be made available to the California Station.

(1) The installation must be made in uniform soil. The soil should be uniform areally, and should have as little profile development as it is possible to find. The latter precaution is important, for soil horizon differences can cause inconsistencies in moisture sampling that may be serious.

(2) Install at least three sets of soil-units in a single study area. This means at least three soil-units at each depth studied. Such replication is necessary because of random soil or moisture variations which occur even within supposedly uniform areas. The magnitude of these differences can be detected by replicated soil-units and replicated sampling such as is described below.

(3) Place soil-units at such depths as to (a) be below the surface horizon, which varies most in organic content and density, (b) be within the horizon of most uniform soil and, (c) be within the horizon which is subject to relatively rapid drying by evaporation and transpiration. These three conditions cannot always be met to complete satisfaction in any one soil horizon, but the best compromise can usually be found if the soil-units are placed between 6 inches and 18 inches deep. A "stack" of several units can usually be placed vertically within this layer.

(4) Establish a uniform vegetation cover on the area, so as to insure uniform evapo-transpiration losses throughout. Heavy water-using vegetation is best for this purpose because it will make possible the greatest number of soil-drying cycles within the period of study. If desired, the soil may be kept bare and evaporation alone relied upon to dry the soil. If this is done, the study area should be surrounded by a trench dug deeper than the maximum soil-unit depth. This is necessary so that roots entering the area from outside will be cut. The trench should be refilled after digging, and opened occasionally during the course of the study.

(5) Determine soil-moisture content at the depths of the soil-units periodically. Sampling can be done at fixed intervals or when resistance measurements made on the soil-units indicate that the soil moisture has changed. The soil at all depths sampled should, if possible, be allowed to dry to the wilting point between irrigations. Irrigation should be uniform over the entire area and sufficient to wet the soil well below the greatest depth of sampling.

Soil-moisture samples should be taken at least in triplicate at the depth of each soil-unit. An auger or soil tube can be used. Samples should not be taken less than 6 inches from a stack of soil-units so that the sampling hole will not affect the units. The sampling holes should be re-filled with well-tamped soil like that removed. Each hole should be marked to avoid the possibility of sampling there again.

If the stacks of soil-units are placed in a triangular pattern, sampling can be done in the same pattern, so that the triangles, in effect, interlock. Repeated samplings will thus eventually form a circle.

(6) It is desirable to continue records on the study area for several years, to learn whether any change develops in the relation of soil-unit resistance to soil-moisture content.

CALIBRATION OF SOIL-UNITS

The relation between soil-moisture content and soil-unit resistance must be determined for each soil in which the soil-unit is to be used. The relation can be determined either in the field where the soil-unit is buried or in the laboratory. The two methods are as follows:

I. Field Calibration

This method involves repeated soil-moisture sampling in the immediate vicinity of each soil-unit. In locations where soil moisture goes through only one or two drying cycles each year, field calibration is likely to be a lengthy affair. But in some cases, such calibration may be more feasible than calibration in the laboratory.

The important considerations in field calibration are these:

(1) Sample as close to the soil-unit as possible, and at the same depth, so as to sample soil moisture representative of that at the soil-unit. But do not sample less than 6 inches from the unit.

(2) Take as small a sample as possible so that repeated samplings will not invalidate the area being studied.

(3) Take duplicate soil-moisture samples, if possible.

(4) Re-pack sample holes with soil of the same kind, packed to the same density, as that removed.

(5) Sample frequently enough to insure adequate coverage of the soil-moisture range, and to minimize the experimental error of the sampling.

(6) Continue sampling through several drying cycles.

II. Laboratory Calibration

This method is based upon that described by O. J. Kelley in Soil Science 58: 433-440: 1944.

(1) Make a box 2 inches high, 1.6 inches wide and 1.6 inches thick. The 1.6- by 1.6-inch bottom and the two sides are to be made of .005-inch thick monel sheet and the other two sides of 100 mesh monel screen, soldered to the outside of the monel sheet. (Monel is used because of its resistance to weathering.) Form a piece of monel to slip over the top of the box as a cover. Cut three notches in the top rim of the box to pass the lead wires.

(2) Weigh the box plus cover plus soil-unit.

(3) Place the soil-unit vertically in the center of the box and pack air-dry soil around the unit to fill the box to within $\frac{1}{4}$ inch of the top. The soil is to come from the location the soil-unit is to occupy in the field, and should be packed uniformly in the box to its field apparent density. This will require some practice.

(4) Weigh the filled box plus cover. The oven-dry weight of the soil is calculated from a determination of air-dry moisture content made on a duplicate sample of the same soil. The weight of box, cover, soil-unit, and oven-dry soil now becomes the tare, while the oven-dry soil weight becomes the basis for soil-moisture determinations.

(5) Half-submerge the filled box in distilled water until the soil is saturated. Then dry the outside of the box, cover it, and place it in a tightly closed chamber. (The chamber can be made of a bell-jar resting on a flat plate. Wick-equipped beakers inside are filled with a saturated solution of $Pb(NO_3)_2$, to maintain the air there at 98 percent relative humidity. The soil boxes can rest on a wire rack in the chamber. Insulated wires leading from the chamber make it possible to measure soil-unit resistances while the soil boxes are inside.)

(6) Leave the box in the chamber overnight; then measure the soil-unit resistance, remove it from the chamber, and weigh it for moisture determination.

(7) Expose the box to evaporation in the laboratory until its moisture content has dropped several percent; then replace it in the humidity chamber and leave it there overnight. Measure resistance and weigh it in the morning. This cycle of drying, resting in the chamber, and measurement is repeated until the soil is dry. Resistances must, of course, be corrected to 60° F.

It has been found advantageous to wet and dry the soil in the box once or twice before taking measurements of resistance. This permits the soil to develop a stable structure. It is also advantageous to run the soil through more than one series of drying cycles. The reason for this is that the characteristic moisture: log resistance curve is double-S shaped (see Figure 7) and in the first drying some important points along the curve may be missed.

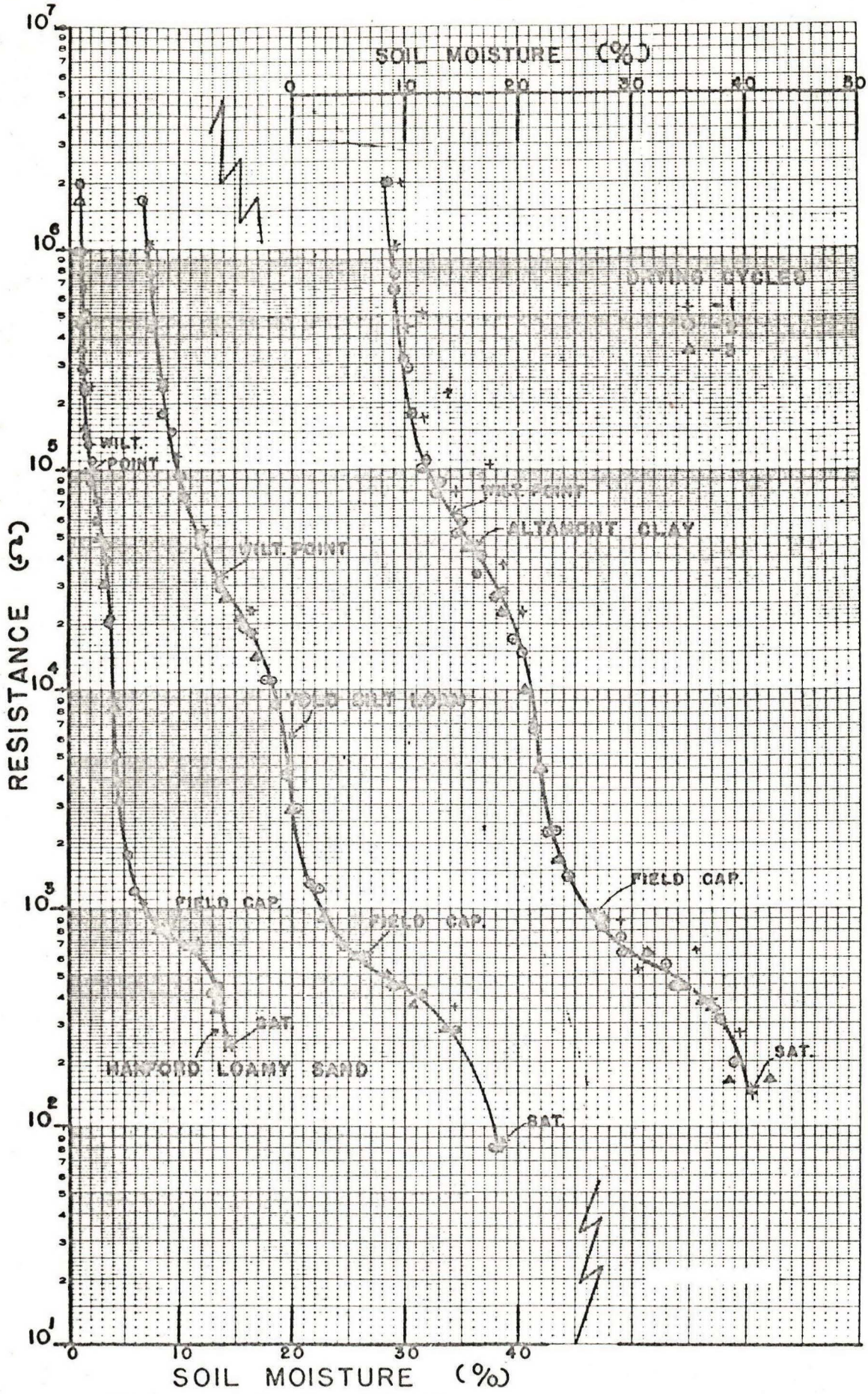


Figure 7.- Sample calibration curves for three California soils. (Soil moisture for the Altamont clay is read on the top abscissa.)